

Damage analysis of asphalt concrete mixtures modified with crumb rubber/CaCo3 Nanocomposite

Farag Khodary ^{*1}, Y. Mohammed², A. Wazeri³

Abstract— Fracture mechanics is one of the most important methodology that can be use to evaluate asphalt concrete mixtures resistance to crack propagation. Semi-Circular Bending (SCB) test is a fast and accurate three-point bending test, which was originally used in rock mechanics, and Viscoelastic material. Asphalt concert material is investigated using semi cracked circular specimen (50 mm radius and 63 mm thickness). Crumb rubber was used as asphalt concrete mixtures modifiers in research with by 10% of the weight of bitumen. CaCo3 was added to the crumb rubber modified heated bitumen by modification level namely 5%, 10%, 15%, 20% and 25%. The result shows that crumb rubber/CaCo3 nanocomposite can be used as asphalt modifier and improve both Penetration and softening point for all modified bitumen. from the point of mechanical properties and fracture resistance modified asphalt concrete mixtures with 15% crumb rubber/CaCo3 nanocomposite have higher than unmodified mixtures by 34.2% and it is appear that modified mixtures with 15% crumb rubber/CaCo3 nanocomposite have two times higher Critical Energy Release Rate (J1C) than unmodified mixtures that means the modified mixtures is more resistance to fracture.

Index Terms— Damage Analysis – crumb rubber – asphalt concrete – Nano CaCo3 nanocomposite - semi cracked circular specimen

1 INTRODUCTION

Asphalt concrete pavements experience damage due to the increase of traffic volume and environmental changes. One of the main compensates of asphalt concrete mixtures is Bitumen which is a visco-elastic material. It is known that temperature and rate of load application have a great influence on its behavior [1]. For example in summer the high temperature soften the bitumen and reduce the stiffness of the mixtures which produce permanent deformation "rutting". In winter cold temperature especially at night stiffen the bitumen and cause pavement crack [2, 3]. Cracking is the most common distresses found in Egyptian roads in recent years that have negative impacts on roadway safety, reduce the service life of the pavement as well as increase the maintenance cost [1, 4].

Nanometric materials have many advantages as it can reduce the operating and maintenance costs of asphalt roads in addition to the long-term performance of the asphalt. It was found that the addition of carbon nano-fiber improves the performance of asphalt concrete mixtures [5]. Nanometric materials were used to improve the properties of Bitumen and found that the use of 2% carbon nano powders has obvious effect on the properties of penetration and viscosity. When comparing the images of atomic force microscope (AFM) indicated that 2% carbon nano powders

modified asphalt has an excellent uniformity structure [6]. Penetration grad of crumb rubber modified bitumen depends on the chemical composition of crude source and parentage of crumb rubber which were added. The presence of rubber in Bitumen has a strong and effective influence of the following properties increase in viscosity, complex modulus (stiffness) as well as elastic response. Adding crumb rubber to the base bitumen the rheological properties of modified asphalt concrete mixtures [7, 8]. Using crumb rubber from cars tiers may be solve a serious environmental problem and help to improve the pavement performance. All properties of crumb rubber modified bitumen binders are largely dependent on rubber concentration. Temperature susceptibility decreases by adding crumb rubber to the unmodified bitumen that lead to real impact in pavement performance [9].

Laboratory investigation into the effects of the interaction between a styrene-butadiene-styrene (SBS) modified bitumen and recycled crumb rubber were studied. The results show that a reduction in cohesion and improve in the resulting modified crumb rubber bitumen in terms of stiffness and viscoelastic balance [10]. Using of the nano CaCo3 with Styrene-Butadiene-Styrene (SBS) modified asphalt appear as a decreasing penetration, an increasing softening point, and a decreasing ductility [11]. Scrap car's tires can be grind and use the resulting powder to improving the properties of asphalt. The rheological testing demonstrated that adding crumb rubber to the base bitumen improved high-temperature performance [12].

Fracture mechanics is the theory that can to predict the crack propagation in the studied material. The importance of using fracture mechanics to study the behavior of asphalt concrete mixtures is to know stress intensities accelerate distress and can dictate failure mechanism. The fracture mechanics techniques are useful to understand the crack distribution in the studied sample

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to produce a mixtures more resistance to fracture [13, 14].

In this work the test method covers the determination of the fracture energy (Gf) of asphalt mixtures by means of the semi circular bend geometry (SCB). The semi circular bend (SCB) test was first proposed to evaluate the fracture properties of asphalt concrete mixtures by Chong and Kurrupu [15]. The SCB specimen is a half disc with a notch that is a-mm long and makes an angle (α) with the vertical axis of the disc. This geometry is simple to produce and can be made from both core samples taken from pavement in-service and laboratory produced cores [16, 17].

2. EXPERIMENTAL WORK

2.1 Materials

Asphalt mixture made up of many materials such as aggregates and bitumen and additives. Many types of additives used in the improvement of the properties of asphalt mixes, such as polymers. In this research two types of additives were used crumb rubber with nano calcium carbonate (CaCo3). The percentage of crumb rubber in asphalt concrete mixtures was 10% by weight of bitumen, which was chosen from our previous work. (CaCo3) nanoparticles were mixed with heated crumb rubber modified bitumen. in this research the percentage of (CaCo3) nanoparticles which was added the modified bitumen with 5%, 10%, 15%,20% and 25% by the weight of modified bitumen.

2.2 Aggregate

Coarse and fine Crushed limestone aggregates with Bulk specific gravities of 2.76 and 2.70 respectively were used in the preparation of the asphalt concrete mixtures. The gradation of the total aggregates mix was obtained by sieve analysis according to the Egyptian Highway Standard Specification (4C). To achieve the required gradations 31 % of coarse aggregate (A) was blended with 31% of Course aggregate (B), 33 % of sand, and 5% of filler, (by weight of total aggregate mix). The gradation of the used aggregate in asphalt concrete mixtures was presented in table (1). Figure (1) presented the gradation of the total mix and specification limits.

TABLE 1

Gradation of the used aggregate according Egyptian highway standard specification (4C)

Sieve size (mm)	Course aggregate (A)		Course aggregate (B)		sand		Filler		Total Mix.	Specification (4C)	
	%P	31%	%P	31%	%P	33%	%P	5%		lower	Upper
25	100	31	100	31	100	33	100	5	100	100	100
19	90	27.9	100	31	100	33	100	5	97	80	100
12.50	33	10.23	100	31	100	33	100	5	79.9	70	90
9.50	4	1.24	87	26.97	100	33	100	5	67.3	60	80
4.75			30	9.3	100	33	100	5	49	48	65
2.36			5	1.55	89	29.37	100	5	37.65	35	50
0.60			1	0.31	50	16.5	100	5	22.8	19	30
0.30					31	10.23	100	5	15.85	13	23
0.15					9	2.97	94	4.7	7.9	7	15
0.075					5	1.65	46	2.3	4.25	3	8

2.3 Bitumen

Bitumen used in preparing asphalt concrete mixtures was 60/70 penetration grade obtained from Suez refinery. The physical properties of the used binder are given in Table (1).

TABLE 2
Properties of Bitumen (60/ 70)

Test	Results	Specifications
Penetration at 25 °C.	67	60-70
Kinematics Viscosity (centistokes at 135 °C)	280	320
Ring and Ball softening point	51.5 °C	45-55
Specific gravity	1.03	1-1.1
Flash point	245 °C	250

2.4 CaCo3 nanoparticles

Morphology and structural of the CaCo3 materials were investigated by transmission electron microscopy (TEM, JEOL JEM-1230 with accelerating voltage of 120 kV) with EDX detector unit attached to the system. Components of the (CaCo3) nanoparticles material elements show the form of varying diameters granules. Variation in diameters of (CaCo3) nanoparticles helps the formation of a strong cohesive structure. The result of transmission electron microscopy (TEM) was presented in figure (1).

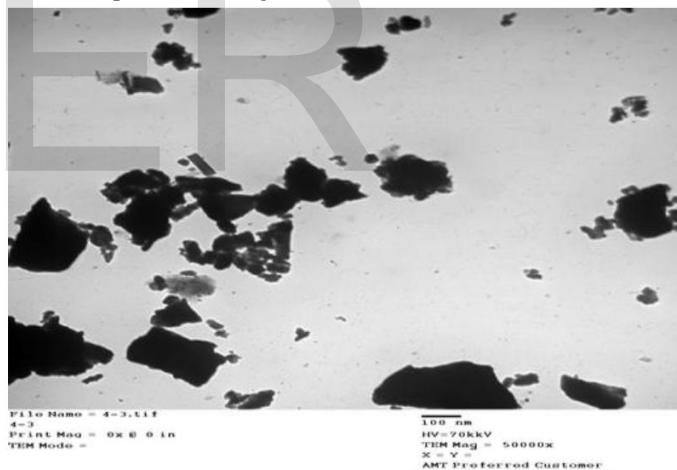


Fig. 1 TEM Micrograph of (CaCo3) nanoparticles

3. BITUMEN AND ASPHALT MIXTURES TESTS

3.1 Penetration and softening point tests

Penetration test is an empirical test that measures the consistency of asphalt at a specified test condition of load, time and temperature. Penetration test was to determine the depth to which a standard needle is applied to the bitumen specimen. Softening point is defined as the temperature at which a bitumen sample can no longer support the weight of a 3.5-g steel ball. Bitumen is viscoelastic materials and when the temperature is raised it gradually become softer and less viscous. For this reason, softening points must be determined [18, 19].

3.2 Compression Test

Compression test is used to measure the compressive strength of asphalt to repeated loads by determine the maximum compression load that make the specimen to failure. The most convenient specimen shape is a specimen of constant circular cross-section [20-23]. A circular cross-section specimen with characteristic dimension of diameter 100 mm, height 60 mm) is used. Loading increased at a rate of 5 mm/minute.

$$\sigma_c = \frac{4P_{max}}{\pi D^2} \tag{1}$$

Where:

- σ_c = Unconfined Compressive Strength,
- P_{max} = Maximum applied compressive load
- D = Diameter of the specimen.

3.3 Static three point flexural test

The Semi-Circular Bend (SCB) Test is used to characterize the fracture resistance of asphalt mixtures based on a fracture mechanics concept. The semicircular specimen is obtained by slicing cylindrical specimens along the central axis to obtain two half cylinders. The test was conducted by repetitively loading a Marshall-sized specimen using computer control electro-hydraulic servo universal testing machine. The static three point flexural test was conducted on notched specimens with initial notch depth of 1 cm. The rate of loading was 1.0 mm / min. The load deflection behaviors of notched specimens were recorded [24-29]. The critical strain energy release rate J_c was determined for each mixture according to the following equation (1). The specimen geometry is shown in Figure (2).

$$J_c = \left(\frac{1}{b}\right) * \frac{\partial U}{\partial a} \tag{2}$$

Where

- b = sample thickness
- a = notch depth
- U = strain energy to failure

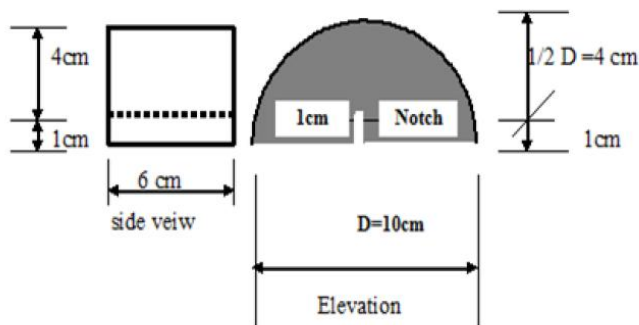


Fig. 2 The semicircular specimen (SCB) of asphalt concrete sample

4. RESULT AND DISSECTION

4.1 Penetration and softening point tests result

The flowing table represents the result of penetration test and softening. Penetration test result measuring the consistency of a bituminous material at a given temperature and softening point helps to know the temperature up to which a bituminous binder should be heated for various road use applications.

TABLE 3

Penetration Test and Softening Test Result		
Bitumen Type / Test	Penetration @ 25 ° C	Softening Point ° C
Unmodified bitumen	70	43
Modified bitumen with 10 CR + 5% CaCo3	65	49
Modified bitumen with 10 CR + 10% CaCo3	63	54
Modified bitumen with 10 CR + 15% CaCo3	51	59
Modified bitumen with 10 CR + 20% CaCo3	49	63
Modified bitumen with 10 CR + 25% CaCo3	48	60

The results shows that in general the increases of modification level with CaCo3 directly increase affect both penetration and softening. With the increase of CaCo3 Nano size from 5% to 25% the penetration decrease 26.1%. On the other hand the increases of CaCo3 nano size from 5% to 25% the softening increase by 28.3%. Greater value of penetration indicates softer consistency.

Higher penetration bitumen is preferred for use in cold climate and smaller penetration bitumen is used in hot climate areas as well as higher softening point indicates lower temperature susceptibility and is preferred in hot climates. The results in Table (1) are re-plotted in Figure (3) and Fig. 4 to show the variation of penetration test and softening with the content of with crumb rubber/CaCo3. Real correlation were found between for penetration test result the correlation were presented in fig. 3 by the following equation (3)

$$y = 70.377e^{-1.683x} \tag{3}$$

$R^2 = 0.9232$ where R is the correlation coefficient and x the content of crumb rubber/CaCo3. On the other hand the correlation between softening and crumb rubber/CaCo3 content. Fig. 4 and equation (4) presented the relation between softening point and crumb rubber/CaCo3 content.

Also good correlation was found and this correlation gives good indicator that can be used to choose the optimum modification level to modify bitumen using crumb rubber/CaCo3.

$$y = 45.317e^{1.4333x} \tag{4}$$

$$R^2 = 0.8647$$

Where: R is the correlation coefficient and x the content of crumb rubber/CaCo3.

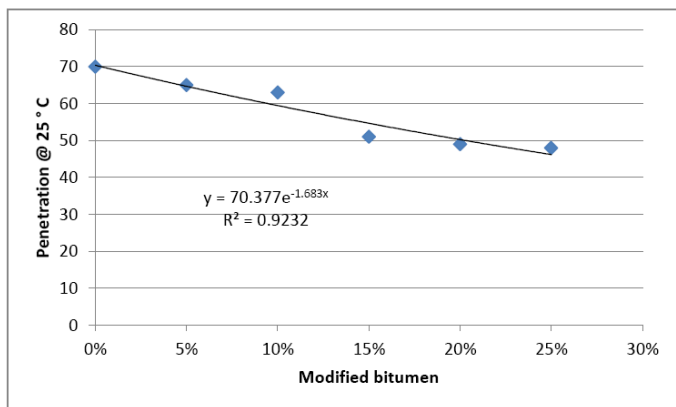


Fig. 3 Penetration tests result

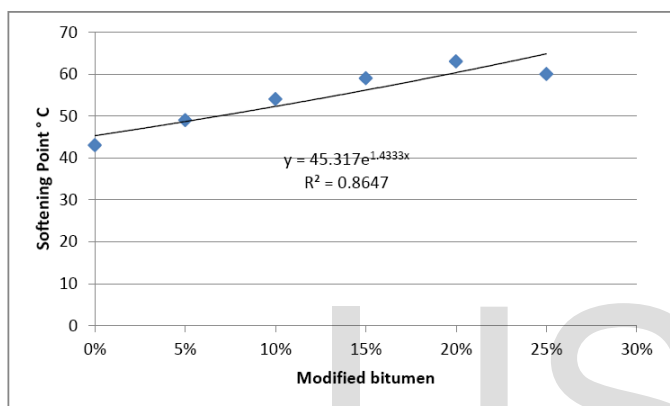


Fig. 4 softening point tests result

4.2 Compression test result

Figure 5 present the Compression test result and it appear that the compressive strength increases with the increase of modifier content upto 15 % crumb rubber/CaCo3.

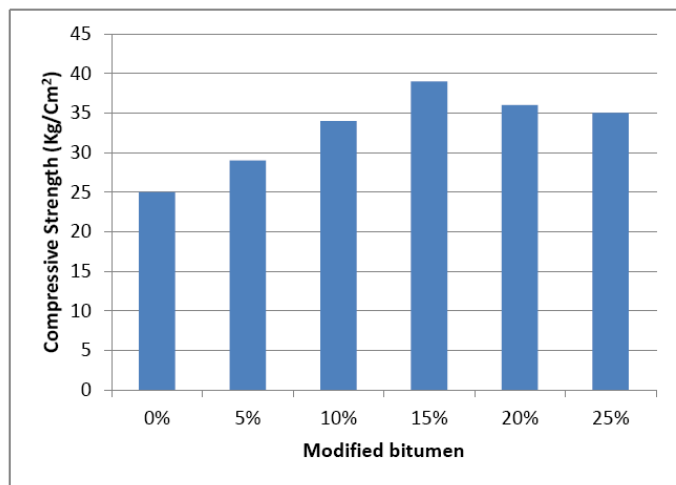


Fig. 5 Compression test result

The compressive strength at 15% crumb rubber/CaCo3 is the maximum value with increase by 34.2% higher that unmodified mixtures. After 15% crumb rubber/CaCo3 modification level the compressive strength start to decrease as a result of the heterogeneity of the mixture formed.

4.3 Static three point flexural test result

Figure (6) and figure (7) present the Area under Load - Deformation curve and Critical Energy Release Rate (J1C) of modified asphalt concrete mixtures. From the figure by increase the modification level the Area under Load - Deformation Curve as well as Critical Energy Release Rate (J1C) increase till 15% modification level. The area under Load - Deformation Curve as well as Critical Energy Release Rate (J1C) start to decrease again with the increase of modification level. Interpret this result as a result of non-homogeneous mixture formation with the increase in the proportion of added. Critical Energy Release Rate (J1C) two times higher than unmodified mixtures which give good indicator that the modified mixtures with 15% crumb rubber/CaCo3 can resist damage.

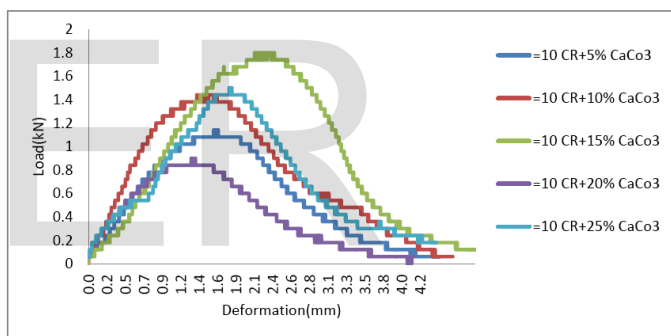


Fig. 6 Load - Deformation curve for crumb rubber/CaCo3 of modified asphalt concrete mixtures.

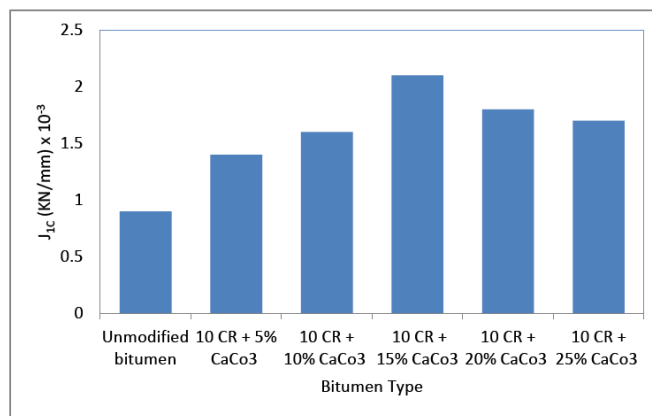


Fig. 7 Critical Energy Release Rate (J1C) of modified asphalt concrete mixtures.

Conclusions

In this paper different tests were present to evaluate the properties of crumb rubber/CaCo₃ modified bitumen and mixtures. From the results and discussions the following conclusions are presented:

- 1) Crumb rubber/CaCo₃ is effective as asphalt concrete mixtures modifiers.
- 2) Using crumb rubber/CaCo₃ improves both penetration and softening point.
- 3) Compressive strength is higher than unmodified mixtures by 34.2%.
- 4) Critical Energy Release Rate (J1C) two times higher than unmodified mixtures.

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